A STUDY OF *IN SITU* CHRONOLOGY IN THE OUTER SOLAR SYSTEM

Final Report

JPL Task MU994

Leslie K. Tamppari, Mission Systems Engineering Section (314)
Timothy Swindle, University of Arizona

A. OBJECTIVES

Determining the age of a feature on a solar system body is one of the most important tasks that can be done, since any model of its evolution has to include time as one of its parameters. Unfortunately, determining the age of a feature is also one of the most difficult things to do *in situ*, and has not yet been attempted on any planetary body. However, the Beagle2 Mars lander is scheduled to perform crude *in situ* dating, and the University of Arizona has been working (under a Planetary Instrument Definition and Development Program grant, with follow-on work recently approved for funding by the Mars Instrument Development Program) to develop a more sophisticated system for Martian applications. The intent of the present study was to study how *in situ* chronology might be accomplished on solid surfaces in the outer solar system, particularly Europa and Titan. Specific objectives were to 1) perform a conceptual engineering study of a noble-gas-based chronology system for Europa, an extension of the system being developed for Mars; 2) identify some of the key issues in sample acquisition and transfer; and 3) study certain scientific questions that have to be addressed in order for particular *in situ* chronology systems to have a chance of working.

B. PROGRESS AND RESULTS

1. Science Data

Two scientific questions were addressed. The first was a study of ^{14}C production and distribution on Titan, the second a study of production rates of noble gases at the surface of Europa. In each case, it appears that there are prospects for *in situ* chronology. Prospects of dating the surface per se are better at Europa, but one of the more intriguing results found was that production of ^{14}C at Titan may produce effects that could be measured by the Huygens probe. More details are shown below:

(1) **^{14}C on Titan:** The results of this study have been published in *Meteoritics and Planetary Science* (see Lorenz et al. under Publications). The abstract of that paper is as follows: "We explore the likely production and fate of ^{14}C in the thick nitrogen atmosphere of Saturn's moon Titan and investigate the constraints that measurements of ^{14}C might place on Titan's photochemical, atmospheric transport and surface-atmosphere interaction processes. Titan's atmosphere is thick enough that cosmic-ray flux limits the productions of ^{14}C: absence of a strong magnetic field and the increased distance from the

Sun suggest production rates of ~9 atom/cm^2/s, ~4x higher than Earth. The fate and detectability of ^{14}C depends on the chemical species into which it is incorporated: as methane it would be hopelessly diluted even in only the atmosphere. However, in the more likely case that the ^{14}C attaches to the haze that rains out onto the surface (as tholin, HCN or acetylene and their polymers), haze in the atmosphere or recently deposited on the surface would be quite radioactive. Such radioactivity may lead to a significant enhancement in the electrical conductivity of the atmosphere which will be measured by the Huygens probe. Measurements with simple detectors on future missions could place useful constraints on the mass deposition rates of photochemical material on the surface and identify locations where surface deposits of such material are 'freshest.'"

(2) **Europa:** There are two fundamentally different dating techniques which can, in principle, be used at the surface of Europa by measuring the chemical composition of a sample and its content of the isotopes of He, Ne, and Ar. One is K-Ar dating, based on the buildup of ^{40}Ar from the decay of radioactive ^{40}K, which measures the length of time the sample has been cool enough to retain Ar. The other is cosmic-ray-exposure dating, based on the buildup of ^{3}He, $^{20,21,22}Ne$ and $^{36,38}Ar$ from nuclear reactions caused by cosmic rays, which measures the length of time a sample has been within 1 to 2 meters of the surface. Various spectroscopic and theoretical studies of Europa have indicated a briny surface for Europa, and the K contents are likely to be enough to make K-Ar dating feasible. This study focused on cosmogenic production, in collaboration with J. Masarik of Bratislava University and R. C. Reedy of the University of New Mexico. Production by high-energy galactic cosmic rays (calculated by Masarik) indicate that production rates comparable to the lunar surface can be expected. Calculations of production by lower-energy charged particles in the Jovian magnetosphere (by Reedy) are in progress. The bottom line is that this should be an effective technique on timescales of 1-100 Ma, which are timescales of interest on the Europan surface. The largest remaining question is the diffusion properties of the noble gases (particularly He) in Europan ice. This work will be submitted as a scientific paper, though it is not complete yet, and no further funding is needed.

2. Other Results

Much of the effort in this study went into trying to define the key engineering considerations for a noble-gas-based *in situ* chronology instrument for the surface of Europa. This study was based on a comparison with the instrument designed for Mars, which utilizes Laser-Induced Breakdown Spectroscopy (LIBS) for elemental analyses; heats a sample to a temperature high enough to release helium, neon and argon (preferably at or above the melting point of the rock); uses a chemical getter to purify the noble gases; and then analyzes the noble gases in a quadrupole mass spectrometry array (QMSA). In considering whether *in situ* chronology can be done on outer solar system bodies, the study started with the Mars concept and considered how working on Europa would be similar or different.

(1) Sample acquisition: D. Yucht of Honeybee Robotics performed tests with existing Honeybee drills into 100 K ice as a part of this study. The results showed that it is possible to drill into such ice using drills Honeybee has already developed. However, there is apparently some localized melting as a result of the process, which can

lead to the drill freezing into the ice if it is stopped. The melting could also be a problem if it heats samples enough to release noble gases, although we had no way to test this in the current study.

(2) LIBS: LIBS has been applied almost exclusively on rock samples so far. However, tests on ice samples are being performed as part of another study by D. Cremers at Los Alamos National Laboratory. The one drawback identified for the LIBS system is that the plume generated by the laser appears to be optimal for pressures of a few torr, like the surface pressure on Mars. In a vacuum, which would be the conditions for a Europan instrument, the plume seems to be comparable to that at Earth's atmospheric pressure. It appears that LIBS would work, although the details of LIBS analyses of ice have not been worked out.

(3) Sample heating: One of the most difficult tasks for the Mars instrument was generating high enough temperatures (1500^0C) in a low-power instrument. Heating will not be a problem for a Europa instrument – the desired temperature will be approximately 0^0C. In fact, the bigger problem will be keeping the sample cold enough until it is ready for analysis.

(4) Gas purification: A key preparation step before analysis of noble gases is removal of the other gases, since noble gases are virtually always only a trace constituent of the gas released. This is often done with chemical getters (the approach planned for the Mars instrument). An alternative approach is to use a cold-trap, at a temperature low enough to condense out the unwanted gases, but high enough not to condense out the noble gases of interest. We would plan to analyze only He, Ne, and Ar, and the high condensation temperature is that of Ar, which is near the temperature of liquid nitrogen. This, in turn, is colder than the temperature of the ice at the surface of Europa, so the cold-trap could simply be a piece of metal in thermal contact with an unheated piece of the surface. The difficulty with this idea is finding a way to get a portion of the instrument in thermal contact with the surface.

(5) Vacuum system: For both the mass spectrometry array and the sample heating and purification portion of the experiment, the gas needs to be in an evacuated, sealed volume. Achieving the necessary vacuum will be easy – the near-surface environment will be at a sufficiently low pressure, so no pumps are required. However, it will be necessary to avoid portions of the spacecraft which may be outgassing, or portions of the surface that are being outgassed by being in contact with the warm spacecraft. In addition, it will be necessary to avoid having surfaces within any vacuum chamber that will be cold enough to act as cold-traps during evacuation, but will then outgas during operation. Finally, high-vacuum valves and seals are required, and none exist that could be expected to perform well at the surface temperature of Europa. This suggests that much of the instrument will need to be in a warm box.

(6) Electronics: The electronics will face two challenges. One is the thermal environment, which will probably require a warm box for virtually all electronics as well. The other, larger, problem is the radiation environment, since Europa is well within the Jovian magnetosheath and is consequently bombarded by energetic charged particles. Radiation hardening is far beyond the present task.

(7) Mass spectrometry: No obvious problems were identified for the mass spectrometry system, beyond those common to all portions of the instrument: the radiation and thermal environment.

(8) Summary: No show-stopping problems were identified. In fact, there are some aspects (reaching the required sample temperature, pumping) that will be far easier on Europa, and those happen to be the activities that require the vast majority of the power for such an instrument on Mars. The most difficult problems are likely to be dealing with the radiation environment (a problem for any instrument operating near Europa) and the thermal environment. The latter is a problem not only because many, if not all, components will need to be warmed above the ambient temperature, but also because the sample will need to avoid that warming.

C. SIGNIFICANCE OF RESULTS

The results indicate that *in situ* chronology on the surface of Europa appears to be feasible, both scientifically and technically, although there are many engineering details left to be solved.

D. FINANCIAL STATUS

The total funding for this task was $100,000, all of which has been expended.

E. PERSONNEL

From the University of Arizona: Dr. Timothy D. Swindle, Dr. Jonathan I. Lunine, Dr. A.J.T. Jull, Dr. Ralph Lorenz, Mr. Rolfe Bode, and Mr. Michael Williams; from Honeybee Robotics, Mr. Daniel Yucht; from the University of New Mexico, Dr. Robert C. Reedy; from the University of Bratislava, Dr. Josef Masarik.

F. PUBLICATIONS AND PRESENTATIONS

[1] R. D. Lorenz, A. J. T. Jull, T. D. Swindle, and J. I. Lunine, "Radiocarbon on Titan," *Meteoritics and Planetary Science,* 37, 867-874, 2002.

[2] T. D. Swindle, "Prospects for Measuring the Age of the Surface of Europa II," Europa Focus Group Workshop 3 (USGS, Flagstaff, Ariz.), May 14-15, 2002.